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Environmental Radioactivity in Greenland in 1972

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A. Aarkrog and J. Lippert

Danish Atomic Energy Commission
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Health Physics Department

Abstract

Measurements of fall-out radioactivity in Greenland in 1972 are reported. Strontium-90 (and Caesium-137 in most instances) was determined in samples of precipitation, sea water, vegetation, animals, and drinking water. Estimates of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Greenland in 1972 are given.

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CONTENTS

ABBREVIATIONS AND UNITS

FP	fission products
pCi	picocurie, 10^{-12} Ci, µµCi
nCi	nanocurie, 10^{-9} Ci, mµCi
mCi	millicurie, 10^{-3} Ci
S. U.	pCi ^{90}Sr/g Ca
M. U.	pCi ^{137}Cs/g K
nSr	natural (stable) Sr
S. D.	standard deviation, $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$
S. E.	standard error, $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$
S. S. D.	sum of squares of deviation, $\Sigma(\bar{x}-x_i)^2$
f	degrees of freedom
s^2	the variance
v^2	the ratio between the variance in question and the residual variance
P	the probability fractile of the distribution in question
$\bar{x}$	mean value
η	coefficient of variation, relative S. D.
Σ	sum
anova	analysis of variance

1. INTRODUCTION

1.1.

In 1972 the sampling programme from the previous years was used with only a few modifications.

1.2.

As hitherto, the samples were collected through the local district physicians and the heads of the telestations. However, as it is not possible to obtain all samples scheduled in the programme, we have got a number of samples through the Royal Greenland Trade Company in Copenhagen.

1.3.

The estimated mean diet in Greenland was unchanged as compared with 1962, i. e., it was in accordance with the estimate given by Professor E. Hoff-Jørgensen, Ph. D., nutritional consultant to the Danish Atomic Energy Commission.

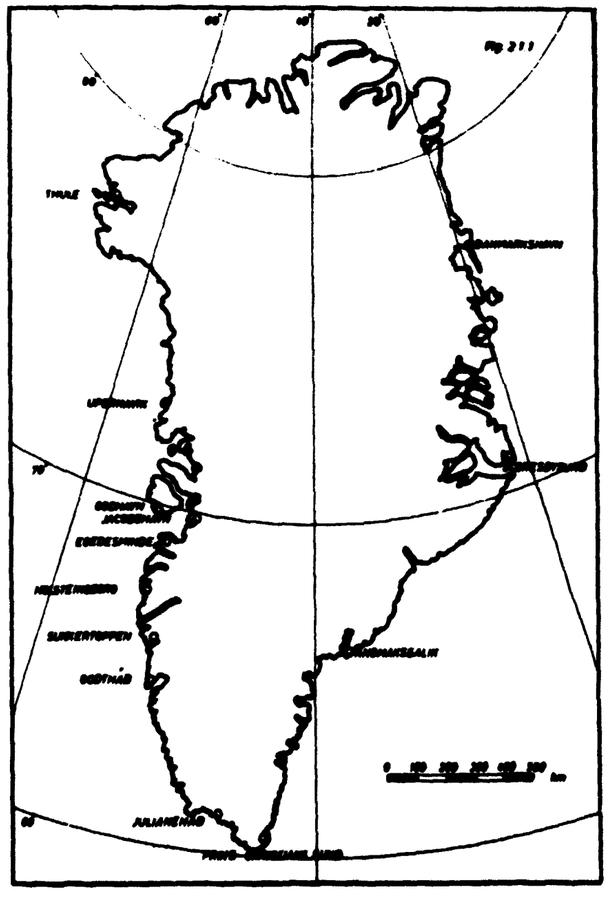

Fig. 1. Greenland

1.4.

The environmental studies in Greenland were carried out along with corresponding investigations in Denmark (cf. Risø Report No. 291)[2] and in the Faroes (cf. Risø Report No. 292)[3].

1.5.

The present report will not repeat information concerning sample collection and analysis already given in ref. 1.

2. RESULTS AND DISCUSSION

2.1. Strontium-90 in Precipitation

Table 2.1.1 shows the results of the measurements.

The total fall-out levels in 1972 at Upernavik, Godthåb, and Kap Tobin were half of the 1971 figures. In Denmark[2] and the Faroes[3] the fall-out levels decreased similarily from 1971 to 1972.

Table 2.1.1

Sr-90 in precipitation collected in Greenland in 1972

Location	Unit	Jan.-Mar.	Apr.-June	July-Sep.	Oct.-Dec.	1972
Upernavik	pCi/l	B 1.12	A 0.68	0.65	0.42	$\bar{x}$ 0.54
Σ 205 mm	mCi/km^2	0.01	0.03	0.03	0.04	Σ 0.11
Godhavn	pCi/l	A 0.68	1.56	1.17	(0.43)**	$\bar{x}$ (0.71)
Σ (478)* mm	mCi/km^2	0.03	0.12	0.13	(0.06)	Σ (0.34)
Godthåb	pCi/l	0.60	1.44	0.66	0.37	$\bar{x}$ 0.69
Σ 595 mm	mCi/km^2	0.07	0.15	0.11	0.08	Σ 0.41
Prins Chr.Sund	pCi/l	(0.69)**	0.45	(0.82)**	(0.43)**	$\bar{x}$ (0.59)
Σ (2571)* mm	mCi/km^2	(0.45)	(0.26)	(0.50)	(0.31)	Σ (1.5)
Kap Tobin	pCi/l	0.56	A 0.39	1.01	0.38	$\bar{x}$ 0.58
Σ 585 mm	mCi/km^2	0.13	0.04	0.12	0.05	Σ 0.34

A: relative S.D.: 20-33%; B: relative S.D.: >33%

**) Specific activity calculated from VAR 3 (table 2.1.2)

*) Amounts of precipitation obtained from Danish Meteorological Institute

Table 2.1.2

Analysis of variance of ln pCi Sr-90/l precipitation in Greenland 1972 (from table 2.1.1)

Effect	Source	SSD	f	s^2	v^2	P
Main	Quarters	1.1008	3	0.3669	2.08	>70%
	Locations	0.8153	4	0.2038	1.15	-
2-factor interaction	L x q	1.4134	8	0.1767	7.98	

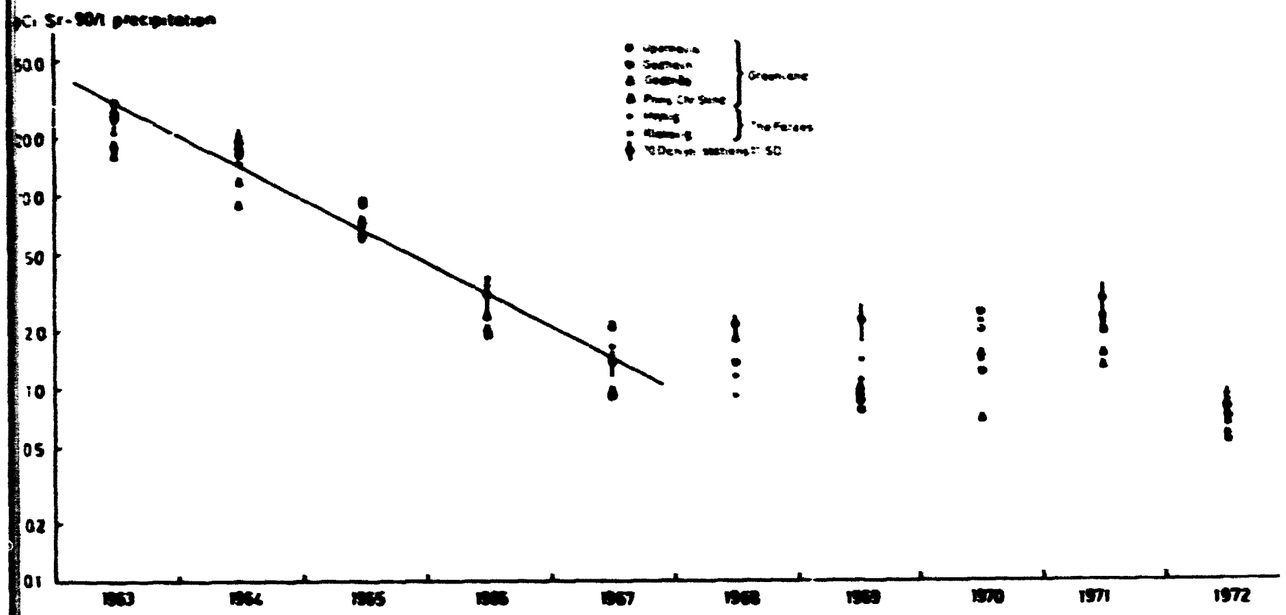

Fig. 2.1.2. Annual specific mean activity of Sr-90 in precipitation collected in Denmark, the Faroes and Greenland in 1963-72. The regression curve $y = 44.7\ e^{-0.76t}$ was calculated from the ten Danish stations in 1963-67

2.2. Strontium-90 in Sea Water

Two samples were obtained from the current sampling along the Greenland coasts. Table 2.2.1 shows the results.

We have earlier (Risø Report No. 247, p. 8)[1] mentioned the relatively high ^{90}Sr levels in sea water from Danmarkshavn. Through the years we

Table 2.2.1

Sr-90 in sea water collected at Greenland in 1972

Location	pCi Sr-90/l	Salinity in o/oo
Danmarkshavn	0.23	25.6
Angmagssalik	0.32	20.3

have observed that various marine samples from the east coast, e.g. Angmagsatter, seals and seaweed, (cf. Risø Reports Nos. 65, 87, 247, and 267)[1] have showed higher levels than samples from the west coast. We think that the surplus activity has a common explanation. It is known that the current along the east Greenland coast carries driftwood from Siberia and we therefore suppose that the higher activity levels in the marine environment of east Greenland arise from the USSR Nuclear Weapons test areas in Northern Siberia (Novaya Zemliya) or from a civilian nuclear source in the northern part of the USSR.

2.3. Strontium-90 and Caesium-137 in Terrestrial Animals

Samples of reindeer and muskox were obtained from the west and the east coast respectively of Greenland. Table 2.3.1 shows the results.

The geometric mean levels in reindeer meat were 1.4 nCi ^{137}Cs/kg and 10 pCi ^{90}Sr/kg. In bone we found 52 pCi ^{90}Sr/g Ca. In fig. 2.3.1 we

Table 2.3.1

Sr-90 and Cs-137 in reindeer and musk ox collected in Greenland in 1972

Month	Location	Species	Sample type	pCi Sr-90/kg	pCi Sr-90/g Ca	nCi Cs-137/kg	pCi Cs-137/g K
	Danmarkshavn	Musk ox I	Meat	4.5 A	47 A	0.09	28
	Danmarkshavn	Musk ox I	Bone	-	34	-	-
	Danmarkshavn	Musk ox II	Meat	6.1 A	41 A	0.07	26
	Danmarkshavn	Musk ox II	Bone	-	77	-	-
May	Egedesminde	Wild reindeer I	Meat	11.4	210	0.84	260
-	Egedesminde	Wild reindeer I	Bone	-	57	-	-
-	Egedesminde	Wild reindeer II	Meat	9.2	54	9.78	3200
-	Egedesminde	Wild reindeer II	Bone	-	190	-	-
-	Egedesminde	Wild reindeer III	Meat	15.5	110	2.23	530
-	Egedesminde	Wild reindeer III	Bone	-	110	-	-
Aug.	Sukkertoppen	Reindeer I	Meat	14.1	170	1.02	250
-	Sukkertoppen	Reindeer I	Bone	-	70	-	-
-	Sukkertoppen	Reindeer II	Meat	8.7	86	0.45	140
-	Sukkertoppen	Reindeer II	Bone	-	67	-	-
-	Sukkertoppen	Reindeer III	Meat	4.2 A	54 A	0.40	94
-	Sukkertoppen	Reindeer III	Bone	-	65	-	-
	Collected by the Royal Greenland Trade Company	Reindeer I	Meat	6.4	69	1.74	500
		Reindeer I	Bone	-	99	-	-
		Reindeer II	Meat	14.1	120	3.13	980
		Reindeer II	Bone	-	140	-	-

A: relative S.D.: 20-33%

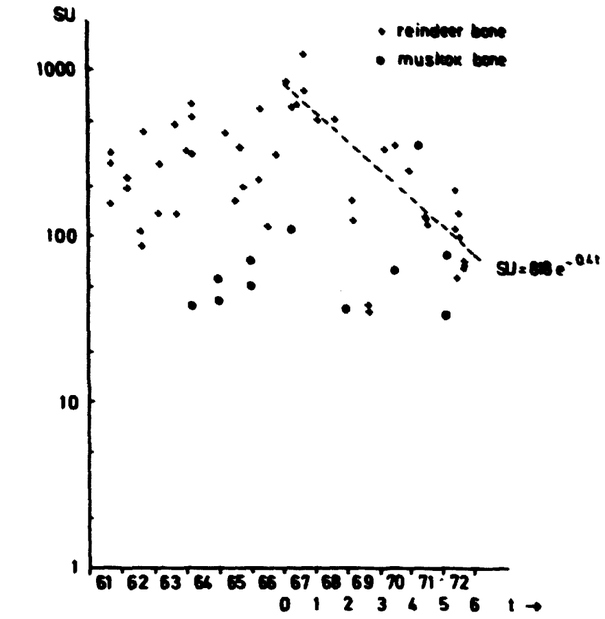

Fig. 2.3.1. Strontium-90 in reindeer and muskox bone 1961-72. The two results from the autumn 1969 were omitted in the calculation of the regression line.

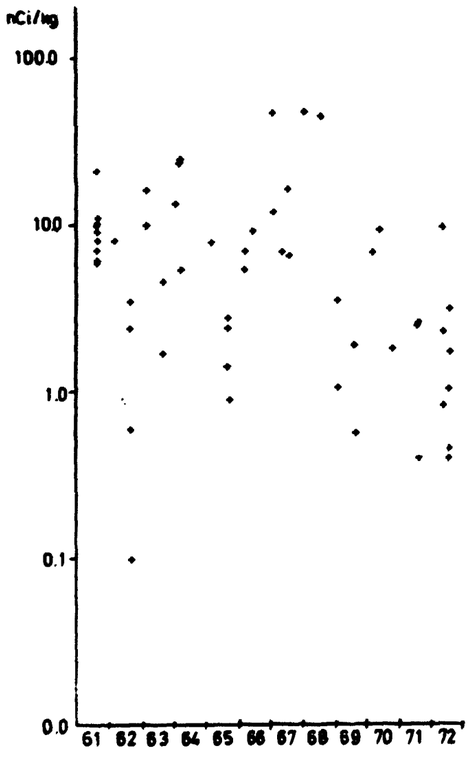

Fig. 2.3.2. Caesium-137 in reindeer meat from Greenland, 1961-72.

have shown the ^{90}Sr levels in reindeer and muskox bone through the years. Since 1967 the reindeer levels have decreased exponentially with an effective halflife of 1.5 - 2 years. The ^{90}Sr content in muskox bone is lower than in reindeer bone. Fig. 2.3.2 shows the ^{137}Cs levels in reindeer meat from Greenland collected since 1961. Although the variance of the figures is large, it is evident that the levels have decreased since 1967.

A single sample of lamb was obtained through the Royal Greenland Trade Company. The meat contained 8 pCi ^{90}Sr/kg (90 S.U.) and 490 pCi ^{137}Cs/kg (210 pCi ^{137}Cs/g K). The bone contained 74 pCi ^{90}Sr/g Ca. The levels were thus a little lower than the 1971[1] figures.

2.4. Strontium-90 and Caesium-137 in Sea Animals

The levels in fish, shrimps, whale, and seal are shown in table 2.4.1. The ^{137}Cs/kg in whale (Lesser rorqual) was remarkably high. In 1970 we found 1700 pCi ^{137}Cs/kg in a whale from the Faroes, but normally the levels are one or two orders of magnitude less.

Table 2.4.1

Sr-90 and Cs-137 in sea animals collected around Greenland in 1972

Month	Location	Species	Sample type	pCi Sr-90/kg	pCi Sr-90/g Ca	pCi Cs-137/kg	pCi Cs-137/g K
Sep.	Angmagssalik	Angmagsetter	Total	1.7 A	0.6 A	48	22
	Egedesminde	Angmagsetter	Total	2.7 B	0.3 B	9±1 B	2.5±0.3 B
	Jacobshavn	Shrimp	Total	3.7 A	0.3 A	6 B	1.6 B
	Egedesminde	Lesser rorqual	Meat	2.0 B	43 B	580	260
	Angmagssalik	Seal	Meat	3.5 B	33 B	42	12
	Angmagssalik	Seal	Bone	-	0.06 B	-	-

2.5. Strontium-90 and Caesium-137 in Vegetation

Lichen, moss, grass and seaweed were collected along the Greenland coast during the summer. Table 2.5 shows the results.

The geometric mean levels in lichen were 7,100 pCi ^{90}Sr/kg and 19,800 pCi ^{137}Cs/kg. These levels are in good agreement with the values observed earlier (cf. Risø Report No. 247[1], fig. 2.5.2). The ^{90}Sr and ^{137}Cs levels in grass also corresponded to the levels found in previous years (cf. Risø Report No. 247[1] fig. 2.5.1).

Since 1964 the ^{137}Cs levels in Greenland lichen have decayed with an effective halflife corresponding to 8 years and in grass with 3 to 4 years.

Table 2.5

Sr-90 and Cs-137 in vegetation samples collected in 1972

Month	Location	Species	pCi Sr-90/kg	pCi Sr-90/g Ca	pCi Cs-137/kg	pCi Cs-137/g K
Autumn	Sukkertoppen	Lichen I	5,100	1,500	33,900	14,700
	Sukkertoppen	Lichen II	6,100	2,100	23,500	10,800
	Marmorilik	Lichen	12,100	710	21,400	5,600
	East Greenland	Lichen	280	6,700	9,100	3,200
	Sukkertoppen	Moss	13,000	2,500	29,800	19,200
	Sukkertoppen	Grass	430	500	1,200	200
	Egedesminde	Clubmoss	3,300	4,100	4,800	770
	Danmarkshavn	Seaweed I	120	7.7	390	40
	Danmarkshavn	Seaweed II	230	14.0	310	27
	Angmagssalik	Seaweed	170	11.0	160	7.2
	Sukkertoppen	Berries	23	310	73	71

2.6. Strontium-90 in Drinking Water

Quarterly samples of drinking water were as previously collected from a number of locations in Greenland. Table 2.6 shows the results from 1972 and fig. 2.6 the results from four of the locations for the period 1962-1972.

As in the previous years, we found it most expedient to choose the geometric mean of all figures, i.e. 0.45 pCi ^{90}Sr/l, as representative of the mean level of ^{90}Sr in Greenland drinking water in 1972.

The drinking water levels in Greenland have in recent years been around 0.5 pCi ^{90}Sr/l. However, in 1971 as well as in 1972 some of the samples from Danmarkshavn were around 2 pCi ^{90}Sr/l. In 1971 the high levels might be attributed to the application of precipitation as drinking water, but in 1972 the ^{90}Sr levels in precipitation were lower than the drinking water levels (cf. table 2.1.1). We anticipate that the drinking water may have come from older ice with a higher concentration of ^{90}Sr than present days precipitation.

Table 2.6

Sr-90 in drinking water collected in Greenland in 1972
(pCi Sr-90/l)

Location	Jan.-Mar.	Apr.-June	July-Sep.	Oct.-Dec.
Danmarkshavn		2.32	0.36	2.72
Upernavik	0.12			0.29
Godhavn	0.23	0.12		0.57
Godthåb	0.74			
Prins Christian Sund	0.60		0.28	

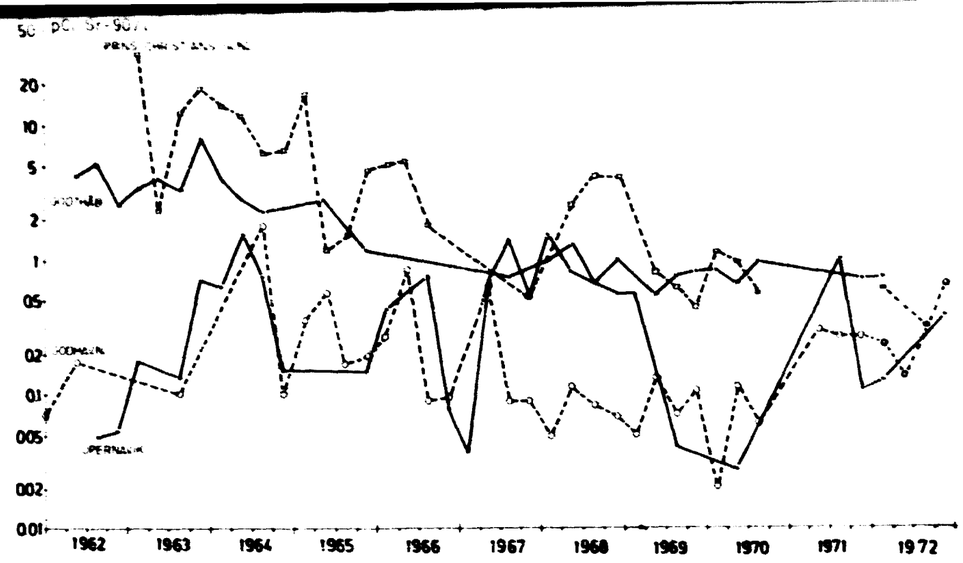

Fig. 2.6. Strontium-90 in Greenland drinking water, 1962-72.

3. ESTIMATE OF THE MEAN CONTENTS OF ^{90}Sr AND ^{137}Cs IN THE HUMAN DIET IN GREENLAND IN 1972

3.1. The Annual Quantities

The estimate of the daily per capita intake of the different foods in Greenland is still based on the figures given in 1962 by Professor E. Hoff-Jørgensen, Ph.D., in Risø Report No. 65[1].

3.2. Milk Products

All milk consumed in Greenland was imported as milk powder from Denmark. The mean radioactivity content in milk prepared from Danish dried milk produced in 1972 was 7.9 pCi ^{90}Sr/kg and 11 pCi ^{137}Cs/kg[2].

Cheese was also imported from Denmark and contained 56 pCi ^{90}Sr/kg and 8 pCi ^{137}Cs/kg.

3.3. Grain Products

All grain was imported from Denmark. It is assumed that only grain from the harvest of 1971 was consumed in Greenland during 1972. The daily per capita consumption was: rye flour (100% extraction): 80 g, wheat flour (75% extraction): 110 g, rye flour (70% extraction): 20 g, biscuits (rye, 100% extraction): 27 g, and grits: 25 g. The content of ^{90}Sr in these five products was 62, 10, 12, 46, and 30 pCi/kg respectively. Hence the mean content of ^{90}Sr in grain products was 32 pCi/kg. The content of ^{137}Cs in the five products was 125, 33, 62, 93, and 62 pCi/kg. Hence the mean content of ^{137}Cs in grain products was 72 pCi/kg.

The activity levels in rye flour (100% extraction), wheat flour (75% extraction), and grits were all taken from tables 5.9.1 and 5.9.2 in Risø Report No. 291[2]. The ^{90}Sr level in rye flour (70% extraction) was calculated by analogy with the level in wheat flour (75% extraction), i.e. as one-fifth of the whole-grain activity. The ^{137}Cs content in rye flour (70% extraction) was calculated as one half of the whole-grain level in rye in analogy with the ratio between ^{137}Cs in whole wheat grain and in wheat flour (75% extraction)[2]. The ^{90}Sr and ^{137}Cs contents in biscuits were calculated by dividing the levels of the rye flour (100% extraction) by 1.35, since 1 kg flour yields 1.35 kg bread[2].

3.4. Potatoes, Other Vegetables, and Fruit

The Danish mean levels for 1972 were used[2] as the local production is insignificant compared with the imports from Denmark.

The Danish mean levels were: in potatoes 2.9 pCi ^{90}Sr/kg and 4.9 pCi ^{137}Cs/kg, in other vegetables 11.6 pCi ^{90}Sr/kg and 2.4 pCi ^{137}Cs/kg, and in fruit 2.9 pCi ^{90}Sr/kg and 4.0 pCi ^{137}Cs/kg.

3.5. Meat

Nearly all meat consumed in Greenland is assumed to be of local origin. Approx. 10% comes from sheep, 5% from reindeer, 60% from seals, 5% from whales, and 20% from sea birds and eggs.

The activity in reindeer and lamb was estimated from 2.3. Seals and whales were estimated from 2.4, and sea birds and eggs were estimated to have contained the same as in 1969, i.e. 0.14 pCi ^{90}Sr/kg and 90 pCi ^{137}Cs/kg. Hence the mean levels in Greenland meat from 1972 were 10.7 pCi ^{90}Sr/kg and 191 pCi ^{137}Cs/kg.

3.6. Fish

All fish consumed was of local origin, and the mean levels from 2.4 were used, i.e. 2.0 pCi ^{90}Sr/kg and 21 pCi ^{137}Cs/kg.

3.7. Coffee and Tea

The Danish figures for 1971[2] were used for coffee and tea, i.e. 24 pCi ^{90}Sr/kg and 106 pCi ^{137}Cs/kg.

3.8. Drinking Water

The geometric mean calculated in 2.6 was used as the mean level of ^{90}Sr in drinking water, i.e. 0.45 pCi ^{90}Sr/l. The ^{137}Cs content was as previously[1] estimated at 1/4 of the ^{90}Sr content, i.e. approx. 0.1 pCi ^{137}Cs/l.

Tables 3.1 and 3.2 show the diet estimates of ^{90}Sr and ^{137}Cs respectively.

Table 3.1

Estimate of the mean content of Sr-90 in the human diet in Greenland in 1972

Type of food	Annual quantity in kg	pCi Sr-90 per kg	Total pCi Sr-90	Percentage of total Sr-90 in food
Milk and cream	78	7.9	616	11.9
Cheese	2.5	56	140	2.7
Grain products	95.6	32	3059	59.1
Potatoes	32.8	2.9	95	1.8
Vegetables	5.5	11.6	64	1.2
Fruit	13.5	2.9	39	0.8
Meat and eggs	45.6	10.7	488	9.4
Fish	127.6	2	255	4.9
Coffee and tea	7.3	24	175	3.4
Drinking water	548	0.45	247	4.8
Total			5178	

The mean annual calcium intake is estimated to be 560 g (approx. 200-250 g creta praeparata). Hence the Sr-90/g Ca ratio in Greenland total diet in 1972 was 9.2 S.U. and the daily intake 14.2 pCi Sr-90.

Table 3.2

Estimate of the mean content of Cs-137 in the human diet in Greenland in 1972

Type of food	Annual quantity in kg	pCi Cs-137 per kg	Total pCi Cs-137	Percentage of total Cs-137 in food
Milk and cream	78	11	858	4.2
Cheese	2.5	8	20	0.1
Grain products	95.6	72	6883	34.1
Potatoes	32.8	4.9	161	0.8
Vegetables	5.5	2.4	13	0.1
Fruit	13.5	4.0	54	0.3
Meat and eggs	45.6	191	8710	43.1
Fish	127.6	21	2680	13.2
Coffee and tea	7.3	106	774	3.8
Drinking water	548	0.1	55	0.3
Total			20208	

The mean annual potassium intake is estimated to be approx. 1200 g. Hence the Cs-137/g K ratio becomes 17 pCi Cs-137/g K. The daily intake in 1972 from food was 55 pCi Cs-137.

3.9. Discussion

As previously, the most important ^{90}Sr source in the diet in Greenland was grain products, which contributed 59.1% of the total ^{90}Sr content of the diet. Milk and meat came next in importance, contributing 11.9 and 9.4% respectively. Approx. 80% of the ^{90}Sr in the food consumed in Greenland in 1972 came from imported Danish food.

Meat was as previously the most important ^{137}Cs source in the Greenland diet in 1972, contributing 43.1% of the total content. Approx. 60% of the ^{137}Cs in the Greenland diet in 1972 came from local products.

As compared with the 1971 figures, the ^{90}Sr content in the total diet in 1972 was 20% higher than the 1971 level, while the ^{137}Cs level was nearly the same in 1972 as in 1971.

To estimate the maximum per capita intakes of ^{90}Sr and ^{137}Cs in Greenland in 1972 we will suppose, as in the previous years[1], that the only grain product consumed by a person was dark rye bread, that all his meat came from reindeer, and that his drinking water was rain water with a specific mean activity of 0.6 pCi ^{90}Sr/l and 1.0 pCi ^{137}Cs/l (cf. table

2.1.1). His daily intake of ^{90}Sr would thus be 22 pCi (14 S.U.) and his ^{137}Cs intake 222 pCi/day (if we use the quantities in tables 3.1 and 3.2). At the lower limit we can imagine someone who ate white bread and seal meat and drank water with hardly any activity (e.g. water formed by the melting of old ice). In this case the daily intakes would be 7 pCi ^{90}Sr (4.5 S.U.) and 26 pCi ^{137}Cs. Hence the ratios between the levels in the maximum and the minimum diets become 3 for ^{90}Sr and 8.5 for ^{137}Cs.

The ^{90}Sr content of the Greenland diet was a little higher than the estimated Danish mean content[2], and 70% of the Faroese level[3]. The ^{137}Cs level in the total diet in Greenland was nearly twice as high as that of the Danish diet and 3.5 times lower than the Faroese diet level.

4. CONCLUSION

4.1.

The ^{90}Sr fall-out rates in 1972 were the following: Godhavn: approx. 0.3 mCi $^{90}Sr/km^2$; Godthåb: 0.4 mCi $^{90}Sr/km^2$; Prins Christians Sund: approx. 1.5 mCi $^{90}Sr/km^2$; Upernavik: 0.1 mCi $^{90}Sr/km^2$. The accumulated fall-out levels by the end of 1972 were estimated at approx. 28 mCi $^{90}Sr/km^2$ at Godhavn, 40 mCi $^{90}Sr/km^2$ at Godthåb, 145 mCi $^{90}Sr/km^2$ at Prins Christians Sund, and 17 mCi $^{90}Sr/km^2$ at Upernavik.

4.2.

The food consumed in Greenland in 1972 contained on the average 9.2 pCi $^{90}Sr/g$ Ca, and the daily mean intake of ^{137}Cs was estimated at 55 pCi. The most important ^{90}Sr contributors in the diet were grain products, meat, and milk products, together accounting for approx. 80% of the total ^{90}Sr content of the diet. Caesium-137 came mainly from meat (reindeer and lamb), grain products, and fish, contributing 81% of the total ^{137}Cs content of the diet.

4.3.

Neither ^{90}Sr analyses on human bone samples nor ^{137}Cs determinations by whole-body counting have until now been carried out on the population of Greenland. Considering the estimated ^{90}Sr levels in the diet, it seems probable[4], however, that the 1972 ^{90}Sr levels of humans in Greenland were on the average rather similar to those found in Denmark, i.e. the mean levels in human bone in Greenland were approx. 1-2 S.U. in newborn children, 2-3 S.U. in infants, 1-2 S.U. in children and teen-agers, and 1-2 S.U. in adults (vertebrae).

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